Computational Modeling of Human Multiple-Task Performance

Final Report
Project N00014-03-1-0009

David E. Kieras
University of Michigan

20060131 297

Report No. TR-05/ONR-EPIC-16

Period Covered: 1 October 2002 – 30 September 2005

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 11 January 2006	3. REPORT TYPE AND DATES COVERED Final Report 1 October 2004 – 30 September 2005	

4. TITLE AND SUBTITLE
Computational Modeling of Human Multiple-Task Performance

5. FUNDING NUMBERS
N00014-03-1-0009

6. AUTHOR(S)
David E. Kieras

03PR00035-03

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Michigan Division of Research Development and Administration, Ann Arbor, MI 48109

8. PERFORMING ORGANIZATION REPORT NUMBER

FR-05/ONR-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research (Code 342)
875 N. Randolph St.
Arlington, VA 22217-5660

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*

This is the final report for a project that was a continuation of an earlier, long-term project on the development and validation of the EPIC cognitive architecture for modeling human cognition and performance. The report summarizes the results and lists the products and publications resulting from the project. These including the modeling system software, tutorials, fundamental architecture development, modeling of visual search, and empirical work on working memory and procedure learning.

14. SUBJECT TERMS
Cognitive Architecture, Human Performance Modeling

15. NUMBER OF PAGES
8

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

Final Report

Computational Modeling of

Human Multiple-Task Performance

ONR Grant N00014-03-1-0009

Period Covered: 1 October 2002 – 30 September 2005

David Kieras, Principal Investigator

David Meyer, Co-Principal Investigator

Introduction

This is the final report for a project on the development and validation of the EPIC cognitive architecture for modeling human cognition and performance. It was a continuation of an earlier decade-long project, Computational Modeling of Human Multiple-Task Performance and Mental Workload (N00014-92-J-1173), conducted by the same two PIs, and so shares much of the same title, although the specific work addressed different topics. This extended activity produced a large number of products and accomplishments; however, this report documents the outcome of only this specific continuation project.

Goals and Summary of Results

The overall goal of this line of work was to develop the EPIC cognitive architecture for modeling human cognition and performance and demonstrate its validity through detailed comparison with empirical data. The report summarizes the results and lists the products and publications resulting from the project. These including the modeling system software, tutorials, fundamental architecture development, modeling of visual search, and empirical work on working memory and procedure learning.

In this project, we had the following specific goals, accomplished as follows:

Tutorials. We made the software and modeling methodology available to a wider audience through tutorial materials and tutorial presentations. Two tutorials were prepared and presented under this project; one was presented at the 2004 International Conference on Cognitive Modeling (ICCM), and focused on using the EPIC software system to create cognitive models.

Kieras, D. & Hornof, A. (2004). Building cognitive models with the EPIC architecture for human cognition and performance. Full-day tutorial presented at the International Conference on Cognitive Modeling, Pittsburgh, July 30-August 1, 2004. The materials can be downloaded from: ftp://www.eecs.umich.edu/people/kieras/EPICtotorial

The second was an online seminar on cognitive modeling for user interface design, presented with Prof. Bonnie John of Carnegie-Mellon University, with the assistance and moderation of Dr. Lisa Neal. The materials were developed under the support of this and other projects, while direct support for the actual online presentation was provided under separate ONR funding.

Kieras, D., John, B., & Neal, L. (moderator). (2005). Seminar on Cognitive Modeling for User Interface Design. Online tutorial presented Feb. 28-Mar. 2, 2005. Materials and presentations arehived at http://www.cs.cmu.edu/~bej/CognitiveModelingForUIDesign/. PI's work leading to this seminar and preparation of the materials were covered by this project; online presentation expenses were covered by ONR grant number N00014-05-1-0387 to David Kieras and Lisa Neal.

Software development. Further development of the modeling software system was pursued to make it available on multiple platforms. This was done in conjunction with presentation of the ICCM 2004 tutorial on using EPIC, where both Macintosh and Windows versions of the modeling system were made available. The complete versions of the software have been made available on request to interested researchers. The tutorial versions of the software can be downloaded from:
ftp://www.eecs.umich.edu/people/kieras/EPICtutorial

Visual search modeling. Extensive modeling of visual search tasks revealed basic properties of the visual system. These results have been presented in a few specialized conferences, and await completion and presentation in a wider venue and publications. These presentations can be downloaded as:
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasONR2005.pdf
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasSoarWkshp2005.pdf
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasVisualSearch2003.pdf
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasVisualSearch2005.pdf

Revision of motor systems. A reassessment of fundamental architectural concepts of the motor system was conducted and incorporated into corrected versions of the models. Continuation of this work is underway to determine the generality of the earlier findings, and the results will be incorporated in the descriptions of the EPIC architecture and then presented in future publications and presentations of models where it is relevant. The current best summary of this work is found in presentations:
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasONR2005.pdf
ftp://www.eecs.umich.edu/people/kieras/EPIC/KierasSoarWkshp2005.pdf

Finalization of earlier work on visual working memory. This takes the form of an archival publication first-authored by David Fencsik, which is in progress:

Fencsik, D. E., Seymour, T. S., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (In process). Representation and processing of objects and object features in visual working memory. Submitted to *Journal of Experimental Psychology: Human Perception and Performance*, 2005. Currently under revision.

Empirical and modeling work on human verbal working memory. This appears in publications and presentations first-authored by Shane Mueller and Adam Krawitz; additional journal articles are in process:

Mueller, S. T., Seymour, T. L., Kieras, D. E., & Meyer, D. E. (2003). Theoretical implications of articulatory duration, phonological similarity, and phonological complexity effects in verbal working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29,* 1353-1380. Available at http://www.umich.edu/~bcalab/documents/MuellerSeymourKierasMeyer2003.pdf

Krawitz, A., Mueller, Shane T., Kieras, David E., & Meyer, D. E. (2004). Executive control operations for updating verbal working memory. Poster presented at the meeting of the Psychonomic Society, Minneapolis, MN, November, 2004. Downloadable from: ftp://www.eecs.umich.edu/people/kieras/EPIC/KrawitzEtAl2004.pdf

Human learning of procedural knowledge. A new set of concepts concerning the mechanisms of human learning in production-rule architectures was developed, and novel empirical data on basic procedural learning was collected, which calls into question many fundamental assumptions about learning that are incorporated in current cognitive architectures. This work appears in publications and presentations first-authored by Stephen Lacey; journal articles are in process. A representative presentation is:

Lacey, S. C., Krawitz, A., Kopecky, J. J., Kieras, David E., & Meyer, D. E. (2004). *Routine procedural recipes for rapid learning in choice-reaction tasks.* Poster presented at the meeting of the Psychonomic Society, Minneapolis, MN, November, 2004. Downloadable from: ftp://www.eecs.umich.edu/people/kieras/EPIC/LaceyEtAl2004.pdf

Technology transfer activities. Multiple lines of work in separately-funded projects demonstrated the utility of EPIC modeling for modeling complex visual display usage, and technologies were shared with a highly usable system for GOMS modeling developed by Kieras. This work involved NSMRL and SPAWAR, Boeing, and Soar Technology. Representative products of this cross-fertilization between projects is:

Kieras, D. (2005). Fidelity issues in cognitive architectures for HCI modeling: Be careful what you wish for. Paper presented at the *11th International Conference on Human Computer Interaction* (HCII 2005). Las Vegas, July 22-27. Proceedings published as CD-ROM. Downloadable from: ftp://www.eecs.umich.edu/people/kieras/GOMS/KierasHCII05.pdf

Kieras, D.E. (in press). Model-based evaluation. In J. Jacko & A. Sears (Eds.), *The Human-Computer Interaction Handbook* (2nd Ed). Mahwah, New Jersey: Lawrence Erlbaum Associates. Downloadable from: ftp://www.eecs.umich.edu/people/kieras/TA_Modeling/Model-based_eval.pdf

Products

Graduate Student Statistics

Number of Degrees Granted: 1
PI/CoPI Minority Women: 0
PI/CoPI Non-Minority Women: 0
PI/CoPI Minority Men: 0
PI/CoPI Non-Minority Men: 2
Grad Students Minority Women: 0
Grad Students Non-Minority Women: 0
Grad Students Minority Men: 0
Grad Students Non-Minority Men: 4
Post Doctoral Minority Women: 0
Post Doctoral Non-Minority Women: 0
Post Doctoral Minority Men: 0
Post Doctoral Non-Minority Men: 0

Journal Articles

Mueller, S. T., Seymour, T. L., Kieras, D. E., & Meyer, D. E. (2003). Theoretical implications of articulatory duration, phonological similarity, and phonological complexity effects in verbal working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 1353-1380. Available at http://www.umich.edu/~bcalab/documents/MuellerSeymourKierasMeyer2003.pdf

Fencsik, D. E., Seymour, T. S., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (In process). Representation and processing of objects and object features in visual working memory. Submitted to *Journal of Experimental Psychology: Human Perception and Performance*, 2005. Currently under revision.

Mueller, S. T. (In process). A note on the two-second decay conjecture in verbal working memory. Submitted to *Journal of Mathematical Psychology*. Currently under revision.

Mueller, S. T., & Meyer, D. E. (In process). Executive control strategies in verbal working memory: Sources of the disappearing recency effect and other mysteries of immediate serial recall. Submitted to *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 2005. Currently under revision.

Krawitz, A., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (In preparation). Executive control operations for updating verbal working memory. To be submitted to *Journal of Experimental Psychology: Learning, Memory, and Cognition*.

Lacey, S., Krawitz, A., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (In preparation). Made to order: Routine procedural recipes for rapid skill acquisition in choice-reaction tasks. To be submitted to *Psychological Science*.

Book Chapters

Kieras, D. E. (2004). Task analysis and the design of functionality. In A. Tucker (Ed.) *The Computer Science and Engineering Handbook* (2nd Ed). Boca Raton, CRC Inc. pp. 46-1 through 46-25.

Kieras, D.E. (2004). GOMS models and task analysis. In D.Diaper & N.A. Stanton (Eds.), *The handbook of task analysis for human-computer interaction*. Mahwah, New Jersey: Lawrence Erlbaum Associates. 83-116.

Kieras, D.E. (in press). Model-based evaluation. In J. Jacko & A. Sears (Eds.), *The Human-Computer Interaction Handbook* (2nd Ed). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Kieras, D.E. (in press). The cognitive controller: How it might work. In W. Gray (Ed.), *Integrated models of cognitive systems*. Oxford University Press.

Conference Presentations

Fencsik, D. E., Seymour, T. L., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (2002). *Representation, retention, and recognition of information in visual working memory.* Poster presented at the meeting of the Psychonomic Society, Kansas City, MO, November, 2002.

Meyer, D. E. (2003). *New prospects for computational unified theories of cognition and action.* Invited address presented at the meeting of the Midwestern Psychological Association, Chicago, Il, May, 2003.

Mueller, S. T. (2003). *Strategic and architectural loci of the recency effect in immediate serial recall.* Paper presented at the meeting of the Society for Mathematical Psychology, Ogden, UT.

Chipman, S. & Kieras, D.E. (2004). Operator centered design of ship systems. In *Proceedings of Engineering the Total Ship Symposium*, organized by the American Society of Naval Engineers, NIST, Gaithersburg, MD, March 17-18, 2004.

Meyer, D. E. (2004). *Contemporary symbolic computational models as a basis for fundamental insights about human cognition and action.* Invited address presented at the annual conference of the American Psychological Society, Chicago, IL.

Kieras, D. (2004). Design Patterns as Programming Constraints on Modeling with a Cognitive Architecture. In Wayne Zachary (Organizer), What do Design Patterns Have to do with Cognitive Modeling? Panel presented at the 2004 Conference on Behavior Representation in Modeling and Simulation, Crystal City, VA, May 17-20.

Krawitz, A., Mueller, S. T., Kieras, D. E., & Meyer, D. E. (2004). *Executive control operations for updating of verbal working memory.* Poster presented at the Cognitive Science Summer School on Working Memory, Bled, Slovenia.

Meyer, D. E. (2004). *Mind, mathematics, and machines: Symbolic computational modeling of human cognition and action based on Executive-Process Interactive Control.* Invited address presented at the meeting of the Society for Mathematical Psychology, Ann Arbor, MI, August, 2004.

Krawitz, A., Mueller, Shane T., Kieras, David E., & Meyer, D. E. (2004). *Executive control operations for updating verbal working memory.* Poster presented at the meeting of the Psychonomic Society, Minneapolis, MN, November, 2004.

Lacey, S. C., Krawitz, A., Kopecky, J. J., Kieras, David E., & Meyer, D. E. (2004). *Routine procedural recipes for rapid learning in choice-reaction tasks.* Poster presented at the meeting of the Psychonomic Society, Minneapolis, MN, November, 2004.

Kieras, D.E. (2005). Next Generation Model of Perception and Action. Presented at the 25th Soar Workshop, Ann Arbor, MI June 15-17, 2005.

Kieras, D. (2005). Fidelity issues in cognitive architectures for HCI modeling: Be careful what you wish for. Paper presented at the 11th International Conference on Human Computer Interaction (HCII 2005). Las Vegas, July 22-27. Proceedings published as CD-ROM.

Tutorials

Kieras, D. & Hornof, A. (2004). Building cognitive models with the EPIC architecture for human cognition and performance. Full-day tutorial presented at the International Conference on Cognitive Modeling, Pittsburgh, July 30-August 1, 2004. The materials can be downloaded from: ftp://www.eecs.umich.edu/people/kieras/EPICtotorial

Kieras, D., John, B., & Neal, L. (moderator). (2005). Seminar on Cognitive Modeling for User Interface Design. Online tutorial presented Feb. 28-Mar. 2, 2005. Materials and presentations arehived at http://www.cs.cmu.edu/~bej/CognitiveModelingForUIDesign/. PI's work leading to this seminar and preparation of the materials were covered by this project; online presentation expenses were covered by ONR grant number N00014-05-1-0387 to David Kieras and Lisa Neal.

Final Report Distribution List

Susan E. Chipman
Office of Naval Research
875 N. Randolph St.
Arlington, VA 22217-5660

Office of Naval Research
Regional Office - Chicago
230 South Dearborn, Room 380
Chicago IL 60604-1595

Defense Technical Information Center
8725 John J. Kingman Road STE 0944
Fort Belvoir, VA 22060-6218

Naval Research Laboratory
Attn: Code 5227
4555 Overlook Avenue SW
Washington, DC 20375-5320